T&D Automation '94

Why fiber optics makes sense for distribution automation

Harold Kirkham[1]

INTRODUCTION

THIS CONFERENCE is the first of its kind at which non-utility speakers have been allowed. When the conference organizers first contacted the Jet Propulsion Laboratory about furnishing a speaker, the topic they (the conference people) were interested in was AbNET, a communication system developed at JPL for distribution automation application. While this system will be described in the session of which this presentation is a part, my colleagues and I thought it would be useful to provide a background to the development, and a rationale for the work.

That is the purpose of my part of the session, to provide an introduction to the topic of fiber optics as applied to distribution automation. So I will give some general background, and in addition to talking briefly about AbNET, I will describe another fiber optic distribution automation system, one that has been in usc for some time. The second speaker in the session, George Allen of American Electric Power, will examine the requirements on a communication system for distribution automation from the AEP point of view, and discuss the idea of separating the communication functions from the SCADA functions as far as possible. The final speaker, Raj Agrawal of Licom, represents the company that has licensed AbNET from Caltech. He will describe the AbNET protocols, and show how they meet the various requirements. He will also summarize the results of a demonstration of the technology presently taking place in Ohio, at the John Dolan research labs of American Electric Power.

Following these presentations, the speakers will be glad to answer questions from the audience.

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OVERVIEW OF FIBER COMMUNICATIONS

The possibility of using glass fibers for communication was conceived as far back as 1910, when Hondros and Debye[2] showed analytically that a circularly symmetric transverse magnetic mode can be guided by a dielectric cylinder in free space. And although there were demonstrations of the effect from time to time, by the early 1960s there had been no practical applications, since the losses in transmission in what was then considered good optical glass were in the order of 1000 dB/km.

In the mid 1960s, Kao and Hockam, then at Standard Telecommunications Laboratories in England, realized that the losses were not due to an inherent property of the glass, but were in fact caused by impurities. They wrote a seminal paper that examined the economics of optical communication taking into account repeater costs and fiber losses.[3] This set the stage for the commercial development of fiber communication systems, and indicated to the telephone companies in particular the way to achieve the greatest benefit:cost ratio. For a telephone application, the economics are most advantageous under two conditions:

- The distance between repeaters should be maximized. Repeaters are expensive pieces of hardware, and the fewer the better.
- 'l'he bandwidth of the channel should be maximized. In this way the maximum number of calls can be routed on a given channel, and the cost' shared among many subscribers.

Because of these factors, the first widespread use of fiber optics for communications was on the long-distance trunks of the telephone companies. The same driving forces have led to improvements in the performance of the fiber, to the extent that today repeaterless fibers are usable over large distances, and their *bandwidth* easily exceeds the *frequency* of the microwave links most electric utilities are accustomed to in their own trunk systems. At the same time, the cost of the fiber cable has been reduced to the point where it is comparable, on a length-for-length basis, with copper conductor.

What are the implications of these developments? For the phone company it is clear that fiber optics can be used to replace copper trunk cables, and provide greater capability, Submarine optical cables carry more traffic to Europe than do satellites.

Driven by the technology there is an urge to use fiber optics at lower levels in the telephone network, To justify putting a fiber into your home, a multifunction capability called ISDN (integrated service digital network) is being proposed, Because the network is technology-driven, rather than market driven, the initials are also frequently thought to stand for I Still Don't Need.

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[2]Hondros, D and Debye, I?, 1910, *Electromagnetische Wellen an Dielektrischen Drahten.* Ann. Physik. Vol 82, pp 465-470.

[3]Kao, K.C. and Hockam, G.A., 1966. *Dielectric Fiber Surface Waveguides for Optical Frequencies.* Proc IEEE, Vol 113, pp 1151-1158

The distribution automation version owes little to its phone company ancestry: the number of customers cannot be maximized by increasing the bandwidth, and the distance between repeaters is set by the distribution system, not the communication requirements. The advantages of fiber optic communications in distribution automation include immunity to interference, and a dielectric medium.

These were some of the reasons that persuaded PG&E and TU Electric to go with fiber optics, using a system developed by H&L Instruments.

H&L's MULTIDROP SYSTEM

The assumption in the H&L system is that there are a number of RTUS (Remote Terminal Units) that have to be interconnected in order to gather data, and perform control. The fiber becomes the optical equivalent of a telephone system. Optical transceivers serve the RTUS, functioning as tap points that give access to the RTUS, and as repeaters to messages on the optical fiber,

The communication configuration preferred by H&L for the optical system is a loop, with both ends connected to a master station, as in Figure 1.

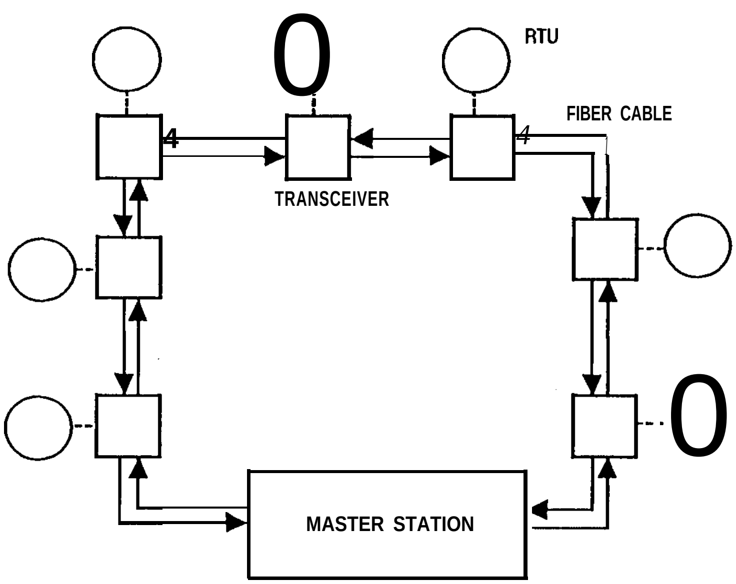

Figure 1. Dual redundant fiber loop system

The RTUS each gain access to the fiber part of the network by means of an RS-232 or RS-485 connection at the transceiver. A message on the optical system is presented to the RTU on this connection. If the RTU recognizes its own address, it will' take the appropriate action, either responding with data, or performing some other function. For maximum reliability the fiber is arranged as a pair of loops, with data flowing both ways in the loop, as in Figure 1. The advantage of this configuration is that a complete break in a fiber cable will not cause a loss of data, and even if a transceiver fails to operate, the other units can be accessed, The optical system can easily be used to bracket the location of faults, This feature is not retained in a radial connection, which is also an option with the H&L approach.

H&L has a number of variations on this basic theme. In one, installed in San Francisco for vault monitoring, the customer required that the optical system should operate in a frequency shift keyed (FSK) mode at 1200 baud, to support some existing equipment.[4] This is an unusual way to operate an optical network, and it makes the network speed artificially low. This speed limit means delays in repeating messages, and that restricts the number of transceivers that can be put in one loop to about 50.

In other versions, the speed on the optical system is about 1 Mb/s, and the transceivers are intelligent. There is no practical limit to the number of RTUS that could be served on one loop. A network like this has been installed by TU Electric at DFW airport for power system reconfiguration.[5]

Note also that while Figure 1 shows the optical system as a loop, it maybe that the loop is a logical one, rather than a physical one. The two ends of the loop can be at different substations. This means that the method is economical of fiber in picking up all the RTUS between two substations.

THE AbNET SYSTEM FOR DISTRIBUTION AUTOMATION

A preliminary version of a generalized communications system for distribution automation can be described, based on a few assumptions.

- First, we assume that the communication system is collocated with the distribution system, both in the substation and along the feeders and laterals, (This is a different assumption from the one above, that there exists a number of RTUS that have to be connected.)
- Second, we assume the use of fiber optics for communications (ie we assume, without a detailed traffic study, that the bandwidth and distance requirements can be met by the fiber technology).
- Third, since the fiber communications channel is in place, we assume that the result of a trade-off study to examine the issue of centralized vs decentralized control would indicate an advantage to centralization at the distribution substation, (Normally, such a trade-off study would examine the effect on overall cost and performance of increasing the amount of distributed computer

[4] For details, see Landman, R.J. and Louie, B., 1991, *A multidrop fiberoptic communications system for supervisory control and data acquisition in underground networks,* Proceedings of the 1991 Power Engineering Society Transmission and Distribution Conference, Dallas, TX, pp 407412.

[5] Seaver, R. C., Kirby, J.K. and Landman R.J., 1993. *Distribution automation at the DFW International airport,* 3rd International Symposium on Distribution Automation and Demand Side Management, Palm Springs, CA, pp 100-107,

power and decreasing the communications capability. Since we are assuming a communication system of considerable capability, it seems reasonable to suppose that the remote nodes need be little more than tap-points and repeaters.)

These assumptions are reasonable. The data rate needed for distribution automation has been variously estimated, but is very small compared to capability of even the most mundane fiber-based network, Data acquisition and control may as well be concentrated at the distribution substation, as an extension of SCADA. With these assumptions, it is possible to define an outline of a generalized distribution automation system. The approach and some system functions are as shown in Figure 2.

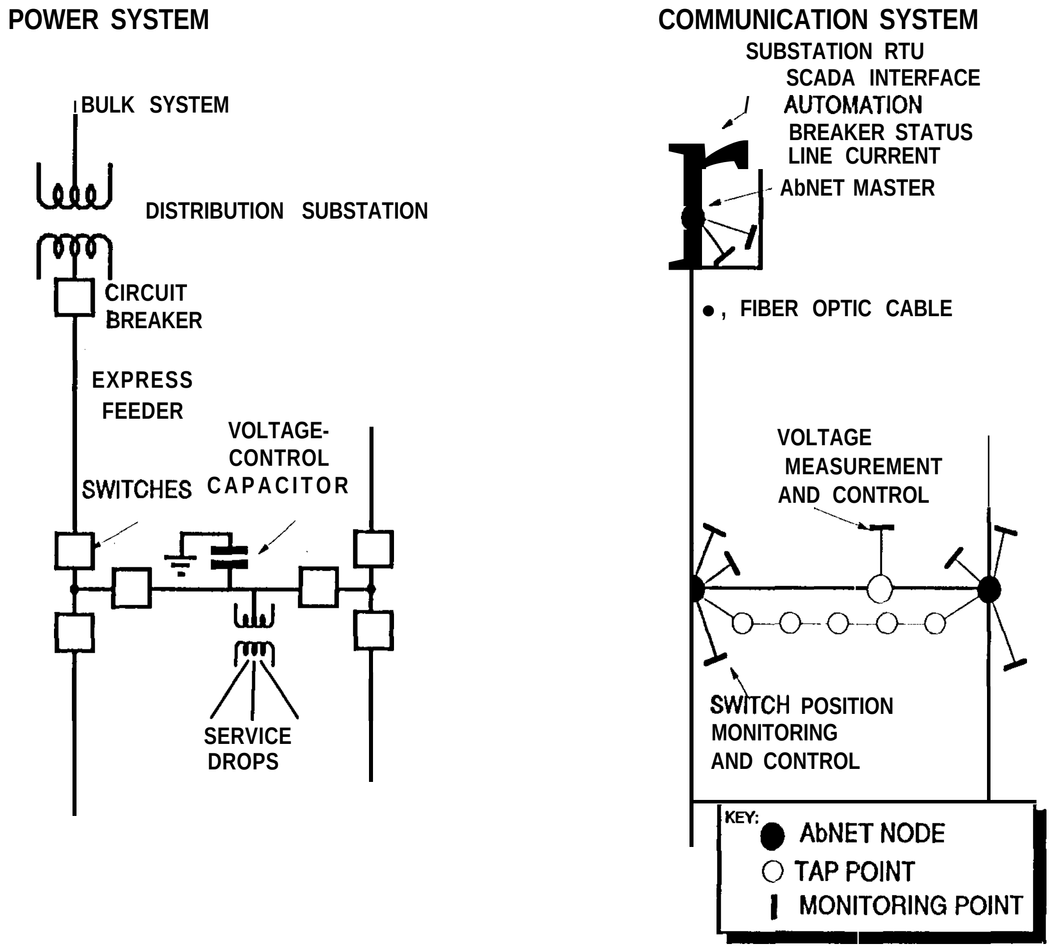

Figure 2. Distribution automation system with fiber-based communications

Note that in Figure 2, the fiber is co-extensive with the power system. Where the distribution system branches, the fiber cable branches. Every place on the power system that something "happens" (a switch, a transformer or a voltage control capacitor, for example) there is a monitoring or control point on the fiber.

Figure 2 shows AbNET nodes. I have mentioned the name before. AbNET is a network that uses a set of protocols designed at JPL specifically for distribution automation. I do not propose to go into the details of the protocols here—they will be discussed by Mr Agrawal later in this session, and can be found in several publications—but I would like to point out why the protocols were developed.

Each of the nodes shown in Figure 2 as AbNET nodes are located at points on the distribution system where one line is connected to another. One reason for locating a node at such a location is that there will typically be something to monitor and control, such as a switch or a circuit breaker. Another important reason is that routing is necessary in the communication system, This needs to be explained.

Unlike copper wires, fibers cannot be tapped arbitrarily. When a wire is tapped, more power is drawn from the source. When a fiber is tapped, the available optical energy has to be split. After a few such taps, the optical energy at downstream locations is much less than at upstream locations. The design of such a network is very difficult, and the approach does not lend itself to modification.

Rather than reduce the optical energy by tapping the fiber, it is conventional to use a repeater to produce copies of incoming messages for each outgoing fiber. In the simplest loop or radial configurations, there are no branches in the optical system. There is one in and one out fiber at each repeater, in each direction, Some networks have branches. This means that a decision has to be made about where any incoming message should be sent.

Any message heading into such a location could be passed to the local RTU, or routed out on one or both outgoing fibers, It is the way this routing is handled that defines one of the unique features of the system we have called AbNET.

We have assumed that the communication system is collocated with the power system. This is because there is a requirement that distribution automation must be able to reach anywhere on the power system. This provides enough information to make it possible to define the general configuration of the communication system that results when the topology is governed by the configuration of the distribution system,

While most power systems are operated radially they are customarily built as a series of open loops. There is almost always an alternative way of bringing power to any given feeder, if the right switching operations are done in the system. The fiber can, of course, be arranged to cross an open power switch, and we assume—for reasons of reliability of communication—that this will generally be done. This means that the fiber optic communication network is arranged not as a conventional ring, star or bus system, but as a series of interconnected loops, with an occasional spur, Figure 3 shows an example of the kind of topology that results if the approach of Figure 2 is extended,

This is an unusual arrangement for a fiber-based communication network, and

[6]For details see Kirkham, H., Johnston, A.R. and Allen, G. Il. 1994. *Design considerations for a fiberoptic, communications net work forpower systems,* IEEE Trans Power Delivery, Vol. 9, No. 1, pp 510-518, or Kirkham, H., Allen, G.D. and Agrawal, R. 1993, *AbNET: An optical fiber solution for distribution automation.* Proceedings of the Third International Symposium on Distribution Automation and Demand Side Management, Palm Springs CA, pp 180-188.

one that offers possibilities that have not been widely explored. The AbNET protocols were designed to serve as an adjunct to a SCADA system, and to exploit the multi-ring configuration to maximum advantage. In addition, a communications protocol that enables each distribution substation to avoid interfering with its neighbors was developed, in such a way that territorial takeover can be supported, should it ever be needed.

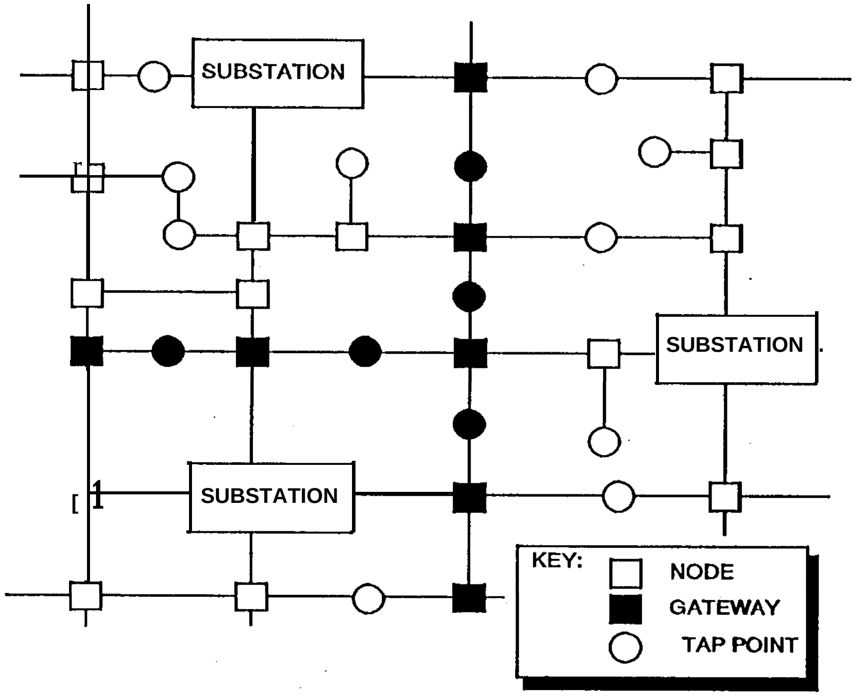

Figure 3. Distribution automation communications topology

AbNET is primarily a method for routing messages in a communication system of arbitrary topology. There is no need to implement the AbNET protocols at a simple tap point on a fiber (such as shown in Figure 3), However, the tap points of Figure 3 do serve as repeaters, so even with low-quality optics, the fiber dispersion (a material property that can limit the capability of long, high-speed systems) is not going to present any limitations. Figure 2 showed an alternative implementation, with the simple tap points on a parallel fiber. In terms of cost, this is probably not very different from the Figure 3 version, because additional fibers can be added to a cable during manufacture at very low incremental cost.

Some of the nodes in Figure 3 are shown as *gateways.* This term is used in communication systems to indicate a node that can separate zones; in this case the zones correspond to the service territories of the distribution substations, In fact, the way AbNET nodes and gateways function is quite novel, and is another of the unique features that define AbNET. Details will be given by Mr Agrawal.

COMPARISON OF FIBER WITH OTHER MEDIA

I have alluded to the various distribution automation functions before, without looking at them in detail. I used the broad brush approach because of the feeling that efficient and cost-effective communications for the distribution system should be able to cope with a wide variety of these applications. It is not my intent in this presentation to examine distribution automation in detail. The topic has been extensively discussed in the literature, and the interested reader is able to find many IEEE Power Engineering Society papers and industry reports.[7]

While they are not the topic of this paper, these applications do normally establish the requirements for the communication system, Meter reading, for example, requires one-way communication with a large number of locations, but relatively little data from each, and that only rarely. Power system monitoring requires access to fewer points, but data must be sent both ways, and promptly. Reconfiguration may require communication with locations in a part of the power system that has become isolated, In general, these various requirements can be used to derive a data rate and a network topology, and to choose a communication protocol.

It seems that in some attempts to demonstrate distribution automation, however, the capability of the communication system has limited the application. Some media are unsuited to access a large number of points, some are capable of only low-rate signaling. Table 1 summarizes these deficiencies.

Table 1. Limitations of Communications media

Medium	Limitation
Power Line Carrier	Too slow (about 80 b/s max) Needs intact power line High error rate
Radio (broadcast)	One way
Radio (VHF and UHF)	Limited coverage Data rate only moderate Multipath and shadowing
Telephone (all kinds)	Access delays Limited number of points

There are institutional issues, too, that argue against several of the common media. For example, CATV and telephone channels involve some sharing of control over the

[7] For a bibliography, see Buch, J.F., Easley, J. H., Ezer, E., McCall, L.V., McLaughlin, P.K., Seebald, R. C., Stovall, J. I?, Triplett, W. E., Wolff, R. I?, 1984, *Bibliography on Distribution. Automation 1969-1982.* IEEE Transactions on Power Apparatus and Systems, Vol. PAS-103, No. 6, pp 1176-1182, or IEEE Working Group on Distribution Automation. (Eds.), 1988, *Distribution Automation.* (IEEE *Tutorial Course text No.* 88EH0280-8-PWR.). *New* York; IEEE.

medium, and some radio options require channel allocations from the FCC, A communications channel that is free of these limitations is to be preferred, other things being equal. Until fiber optics came along, no single medium seemed suitable even for the general purpose monitoring and control task alone.[8]

The Electric Power Research Institute (EPRI) seems to be in agreement, In the *Guidelines for Evaluating Distribution Automation,*[9] it is observed that "A gap exists in that viable distribution communications systems for the fully automated distribution system are not available at the present time. " (page 11-5),

Evidently supporting this view, the IEEE distribution automation Tutorial Course text (see footnote 7 above) observes that "no single communication technology has been demonstrated as being best for all distribution automation needs" (page 17), The text goes on to observe that each automation scheme has unique communication requirements, and therefore a communications system must be engineered on a case-by-case basis, using a combination of media,

The combination selected will depend on a number of factors, including the functions to be implemented, and the nature of the utility. Hilly terrain might rule out the use of radio, for example, and a mixed overhead-underground distribution system might make power line carrier difficult,

For example, a satisfactory feeder automation system can be made based on the use of UHF radio. Low-power UHF radio, operating at about 950 MHz, can provide two way communications for line-of-sight locations. The bandwidth available is not as impressive as the frequency might imply, but signalling rates up to about 10 kb/s can be achieved. However, there is likely to be a good deal of customizing required to make such a system work well in any particular location.

This case-by-case engineering a costly proposition for the utility (which would benefit from standardization, or what we used to call the cook-book approach), and there are still likely to be problems. For example, in the case of UHF radio systems, spectrum limitations can lead to interference. Some relief is found by the use of frequency-hopping, or spread spectrum, However, even with this advanced technique, the throughput is reduced as the number of users increases. Continued growth of the number of users—and remember that in addition to utilities, there are pagers and other unlicensed low-power transmitters—will increase system noise, and further reduce throughput, The limited bandwidth usually means that the system cannot support routine polling of all nodes for data at the same rate as the SCADA system. Some kind of report-by-exception scheme is generally used to reduce the communication traffic.

Report-by-exception schemes use local intelligence to examine local data to see

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[8] For a detailed discussion of the various media, see Fink, D.G. and Beaty, H.W. (Eds), *Standard Handbook for Electrical Engineers. New* York, McGraw-Hill. In particular, the reader is referred to Chapter 10, which includes a section by Landman on SCADA equipment and communications. The Handbook also contains an excellent bibliography.

[9] Bunch, J., 1984. *Guidelines for Evaluating Distribution Automation* (EPRI EL-3728, Research Project 2021-1, Final Report)

if there is anything worth reporting to the polling station. These methods usually break down when there is a widespread problem, because each local set of data seems to the local intelligence to be worth reporting. Just when the data are most needed, the communication system suffers a log-jam!

The usual solution is to instruct the RTUs to go silent, and then to poll the few that may have important data, if these can be determined, or to poll all the RTUS. This may not be very effective: note that report-by-exception was installed in the first place exactly because polling could not be accomplished rapidly.

We will see later that fiber optic systems can easily support routine polling of large numbers of nodes, obviating the need for report-by-exception. Fiber is the missing "single communications technology" for distribution automatic.

COSTS COMPARISON

Based on the ideas developed so far, it is possible to perform cost estimates for the communications system, For any communication network, capital costs consist of two components, the one-off cost of the central unit, and the costs of the remote nodes, and the channel to them, which vary as a function of their number and location.

We may estimate that the cost of the optical central unit, a low-power device, is comparable with or less than the central unit of any other medium, for example a UHF radio transceiver, It may in fact be much less expensive, since no antenna structure is required. The same is true of the remote nodes: the received signal is of such high quality that, in quantity, the hardware may actually be simpler and cheaper than for nodes using other media,

The difference in overall cost between a fiber system and the "conventional" media is mainly the channel cost, which is zero for radio systems and power line carrier, but not for telephone-based systems or fiber optics. We have estimated that the fiber cable can be installed on a typical distribution circuit for less than $3000 per km, Carrying charges at 10% on this amount of money over 30 years are $26/month, This does not seem prohibitive.

A fiber-based system could be installed for roughly the same cost as a dedicated wire system. The one alternative communication medium that was not mentioned in Table 1 was dedicated wire, For the data rates that are needed for distribution automation, it could be argued that a dedicated wire is adequate, I think this is true, However, a fiber based network has the advantage of being all-dielectric. In the power distribution system, where tree and ice damage may be common, and a copious supply of energy is very close, there is much to be said for maintaining dielectric isolation. For a similar cost, the fiber has a large advantage.

It is important to note that the fiber optic system becomes more attractive as the number of applications increases. This is because the channel cost can be considered to be zero once the first application is installed. This is not the case with the other media: if an additional function is required, it is usually necessary to add another communication channel, starting from scratch, For example, suppose a feeder monitoring system is installed, with a node (RTU) every 500 m, To estimate the cost of communications, to the cost of each RTU must be added the cost of 500 m of cable, or $1500. Now, suppose load managements to be added. The central unit and the channel are already in place: all that is needed is the software, and the nodes for load management. We feel that at this point, the fiber-based approach is to be preferred to, say, adding a PLC load management system to a UHF radio feeder control system.

If yet more functions are added, the cost advantage of fiber optics becomes greater still. The conclusion is clear: a fiber optics communication system can be competitive in cost for node spacings that are realistic in many utilities.

CONCLUSIONS

One of the goals of using fiber optics to implement a communication system for distribution automation must be to remove any obstacles that might be presented by the conventional media. Fiber allows the communication engineer to design a system that will meet all the worst-case requirements: that can access as many locations as necessary that can handle the highest data rate likely to be required by any application. Essentially, it is possible to have a communication system that would be the “phone company” for any and all distribution automation applications. As far as possible, the application would not need to know how its messages were delivered, and the communication system would not need to know what the messages contained.

Two fiber-based communication systems that accomplish these goals have been described, Both systems have a channel data rate of over 1 Mb/s, which can support the complete scanning of up to (say) 100 RTU nodes in a second. One approach can operate in a network of any topology-in fact, the network automatically informs the operating system software of the communication network topology, and automatically detects any changes in configuration.

Fiber optics certainly does make sense for distribution automation. In fact, fiber optics may be set to become an enabling technology for distribution automation. Now that commercial fiber optic systems are available, we look forward to some full-capability distribution automation in the near future.

Prepared by the Jet Propulsion Laboratory, California Institute of Technology, for the U.S. Department of Energy, Office of Energy Management Systems, Utility Systems Division, through an agreement with the National Aeronautics and Space Administration.

Harold Kirkham was born in Birmingham, England in 1943. He received a BSC (Hens) in 1966 and an MSC in 1967 from the University of Aston in Birmingham. In 1973 he received a PhD from Drexel University in Philadelphia.

In Philadelphia, he worked at the AC/DC Research Project of the Edison Electric Institute, and continued an interest in the topic of combined AC/DC systems into his PhD work. From 1973 until 1979 he was with American Electric Power, responsible for the data acquisition system at their UHV station in Indiana. In 1979 Dr Kirkham joined the Communications and Control for Electric Power Systems project at the Jet Propulsion Laboratory in Pasadena, CA. Since 1984 he has been Project Manager.

Dr Kirkham's current research interests are largely associated with power system applications of fiber optics, His group at JPL has developed a series of miniature fiber-based instruments to measure both ac and dc electric fields. More recently, they developed the AbNET communications protocols **for communication for distribution automation,**

In the IEEE Power Engineering Society, Dr Kirkham is Secretary-**elect** of the Power Systems Instrumentation and Measurements Committee, and a member of the Fiber Optics Subcommittee of the Communications Committee. He is also Chairman of two Working Groups.